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EFFECTS OF CARBOHYDRATE INTAKE AND LOAD BEARING EXERCISE ON RIFLE MARKSMANSHIP PERFORMANCE

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Authorship Responsibility

I certify that I have participated sufficiently in the conception and design of this work and the analysis of the data (when applicable) as well as the writing of the manuscript, ~~and~~ to take public responsibility for it. I believe the manuscript represents valid work. I have reviewed the final version of the manuscript and approved it for publication. Further, I will produce any data used in the manuscript as requested.

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Robert Moore ______________

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on the Use of Volunteers in Research.

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The combined and separate effects of load bearing exercise and dietary carbohydrate (CHO) levels on rifle shooting were examined. The study consisted of three phases. During each phase participants (15 male soldiers) were randomly and blindly administered one of three experimental ration diets, 250 g, 400 g, or 550 g CHO diet for a four day period. Protein and total kcal remained constant with the CHO and fat contents varying. Participants fired a disabled M-16 rifle equipped with the Noptel ST-1000 marksmanship simulator before and after strenuous load bearing exercise. The exercise consisted of marching on a treadmill for up to 4 hr at a rate of 3.5 mph while carrying a weight of 45 kg. Participants shot at a simulated 100 m target for both speed and accuracy and for accuracy only. Analyses of variance showed shot group tightness (SGT) was significantly impaired ($p \leq 0.05$) following exercise when shooting for accuracy only. Sighting time was reduced following exercise ($p \leq 0.05$). No main effect of CHO level occurred for any marksmanship measure. A significant diet by exercise interaction effect for SGT ($p \leq 0.01$) existed when shooting for accuracy only. A significant deterioration in SGT occurred after exercise while consuming the 250 g CHO diet while no significant differences existed pre to post exercise for the 400 g or 550 g CHO diets. The results of this study indicate that soldiers required to march with loads of 45 kg can expect to display impairments in marksmanship. The most likely explanation for these impairments are muscle fatigue from the exercise resulting in muscle tremor which affects the aiming process. Marches which last two hours or longer are likely to impair subsequent rifle shooting accuracy to a greater degree when consuming a 250 g CHO diet than consuming a 400 g or 550 g CHO diet.

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EXECUTIVE SUMMARY

The combined and separate effects of load bearing exercise and dietary carbohydrate (CHO) levels on rifle shooting were examined. The study consisted of three phases. During each phase participants (15 male soldiers) were randomly and blindly administered one of three experimental ration diets, 250 g, 400 g, or 550 g CHO diet for a four day period. Protein and total kcal remained constant with the CHO and fat contents varying.

Participants fired a disabled M-16 rifle equipped with the Noptel ST-1000 marksmanship simulator before and after strenuous load bearing exercise. The exercise consisted of marching on a treadmill for up to 4 hr at a rate of 3.5 mph while carrying a weight of 45 kg. Participants shot at a simulated 100 m target for both speed and accuracy and for accuracy only.

Analyses of variance showed shot group tightness (SGT) was significantly impaired ($p \leq 0.05$) following exercise when shooting for accuracy only. Sighting time was reduced following exercise ($p \leq 0.05$). No main effect of CHO level occurred for any marksmanship measure. A significant diet by exercise interaction effect for SGT ($p \leq 0.01$) existed when shooting for accuracy only. A significant deterioration in SGT occurred after exercise while consuming the 250 g CHO diet while no significant differences existed pre to post exercise for the 400 g or 550 g CHO diets.

The results of this study indicate that soldiers required to march with loads of 45 kg can expect to display impairments in marksmanship. The most likely explanation for these impairments are muscle fatigue from the exercise resulting in muscle tremor which affects the aiming process. Marches which last two hours or longer are likely to impair subsequent rifle shooting accuracy to a greater degree when consuming a 250 g CHO diet than consuming a 400 g or 550 g CHO diet.

INTRODUCTION

Technological advances have provided sophisticated equipment to enhance both the fighting capability and the health and well being of today's combat soldier. However, much of this equipment is heavy and must be carried into combat on the back of the foot soldier. Knapik et al. (1991) reported that in training exercises at the Joint Readiness Training Center, Ft. Chaffee, AR, soldiers carried an average total load of 40 kg, with maximal loads exceeding 60 kg. These values exceed the U.S. Army Infantry School's recommendations for approach march loads of 45% of body weight or 33 kg for the average soldier (Burba, 1986; Knapik, et al., 1991).

Load bearing exercise may have negative effects on a variety of military performance tasks. Knapik et al., (1991) demonstrated that rifle shooting accuracy was impaired when soldiers performed a maximal effort road march carrying a 46 kg total load. Other research has shown decreases in rifle marksmanship accuracy after intense aerobic exercise (Evans, 1966; Niinimaa & McAvoy, 1983; Tharion, Hoyt, Marlowe, & Cymerman, 1992). The decreased accuracy after exercise in these studies has been attributed to increased body tremors from fatigue and elevated heart rates.

Dietary carbohydrate (CHO) levels can affect the onset of physical fatigue. Research has shown that diets high in CHO content are necessary for optimal performance in endurance related tasks with moderate to high intensities (greater than 60% Vo_{2max}) that last longer than 60 min in duration (Costill, 1988; Coyle & Coggan, 1984). Military field exercises on repeated days have shown muscle glycogen depletion was more pronounced when consuming a low (431 g) CHO diet than a high (593 g) CHO diet (Jacobs, Anderberg, Schele, & Lithell, 1983). In addition to success on an endurance task as described above, CHO intake may also have an impact on secondary tasks involving fine motor movements when these tasks are performed immediately after intense endurance exercise such as running or road marching with a load. Because muscular fatigue is likely to produce tremors which have a negative effect on shooting accuracy, avoiding glycogen depletion by feeding higher CHO diets may reduce the tremors caused by muscle fatigue and contribute to the conservation of marksmanship accuracy in soldiers performing strenuous work. Other motor tasks which involve muscle coordination such as downhill skiing have also been shown to be affected by low level

CHO diets (Brouns, Saris, & Ten Hoor, 1986).

Except for the study of Knapik et al., (1991) there has been little research on the effects of load bearing exercise on rifle marksmanship, or on the interaction of dietary CHO content and rifle marksmanship. The purpose of this study was to examine the combined and separate effects on rifle shooting performance of load bearing exercise and CHO levels in the diet.

METHODS

SUBJECTS

Fifteen healthy, active male soldiers, 19 to 24 ($\bar{X} \pm SD = 20.5 \pm 1.6$ yrs) years of age who were experienced marksmen volunteered to participate in the study. All participants underwent a pre-study physical examination and gave their written informed consent.

GENERAL PROCEDURE

The study consisted of three phases of five days each. During each phase, participants were fed one of three experimental rations in a randomly assigned order. The diets provided either a 250 g, 400 g, or 550 g CHO content daily. Each diet provided 88 g protein and 3600 kcal daily, differing only in CHO and fat content. Participants were blind to the identity of the ration provided. The rations consisted of prototype foods for the Nutrition Sustainment Module ration system being developed by the U.S. Army Natick, Research, Development, and Engineering Center, Natick, MA. This ration has been described in detail previously (Hoyt, et al., 1991).

Each study phase consisted of four days during which the ration was consumed followed by one day in which the treadmill and marksmanship tests were administered. On Days 1-3, participants performed two to three hr road marching exercises over generally level terrain to accustom them to carrying the loaded rucksack. On Day 4, participants completed a single Vo_{2max} test and rested. On Day 5, each participant performed a treadmill march load carriage test (described in detail later). No other physical activity was done during these four days. Each individual study phase was identical except for the diet consumed. A nine-day washout period with self-selected diets was allowed between the various experimental diets.

Of the 13 participants who volunteered for the study, two participants withdrew while four others only completed two of the three experimental periods. This was a result of blisters and other structural injuries to the lower extremities, which occurred during the load bearing training sessions over the preceding test days. Two-way (Diet X Exercise Effects) analyses of variance (ANOVAs) were used to assess significant differences. Between participants ANOVAs were used, since not every participant received each diet. Level of significance was set at a *p* value of .05.

MARKSMANSHIP TEST

Marksmanship performance was quantified with a Noptel ST-1000 (Noptel Ky, Oulu, Finland) laser marksmanship simulator system. The system consists of a laser transmitter attached to the barrel of a disabled M-16 rifle, a laser switch, an optical target, a desk-top computer, and a printer. The laser emits a continuous 0.5 mm, invisible 0.8 µm wavelength beam. A vibration sensor in the laser transmitter detects when the weapon is fired. Shot location of the laser was recorded via its position on the optical target at the time of trigger pull.

Each marksmanship test consisted of a total of 20 shots. Participants shot from a free standing unsupported position at a 2.3 cm diameter circular target 5 m away. This simulated a 46 cm diameter target at 100 m which is similar to the standard 49 cm wide, 100 m military human silhouette target. Participants were instructed to shoot at will for the first ten shots to obtain the best accuracy score possible. For the second ten shots, instructions were to "shoot as quickly as possible without sacrificing accuracy". During the latter assessment, a verbal ready signal was given. Following a randomly varied 1 to 10-second delay, participants shot when a red light located to the left of the target came on.

A computer program based on an algorithm developed from digitized shot records (Marlowe, Tharion, Harman, and Rauch, 1989) was used to convert scores to actual shot distances from target center. These shot distances are 20 times smaller than those typically obtained with a life-sized target at a 100 m distance on an actual shooting range. The X and Y-coordinates for sets of five simulated target hits derived from the computer program were entered into a data file and the following marksmanship parameters were calculated (Tharion, Hoyt, et al, 1992):

Distance from centroid of mass (DCM) = distance (mm) from the center of impact of the shot group to the center of the target.

Shot group tightness (SGT) = area (mm^2) of the shot group, i.e., the maximum horizontal distance (X axis) multiplied by the maximum vertical distance (Y axis) between shots.

Horizontal shot group tightness (HSGT) = distance (mm) from the left-most shot to the right-most shot; i.e., the range along the X axis.

Vertical shot group tightness (VSGT) = distance (mm) from the lowest shot to the highest shot, i.e., the range along the Y axis.

Sighting time (STIME) = time (sec) from illumination of the red light to trigger pull.

LOAD CARRIAGE TREADMILL TEST

The standard U.S. Army load carrying system for individual soldiers was utilized for the load bearing exercise. This system consists of the LC-2 frame to which the rucksack is attached. The frame is compatible with the standard equipment belt to which items such as the canteen, ammo pouches, and other individual equipment items are attached. Approximately 22 kg was carried in the rucksack with the remainder of the weight, 23 kg, distributed on the body (includes BDU's, boots, helmet, and items on the belt) for a total load of 45 kg. The pack system was adjusted to individually fit each subject.

Participants practiced the load bearing exercise daily, both on a treadmill and outdoors during the nine-day period prior to starting each diet and on Days 1-3 of the diet. On Day 4 no load was carried. On Day 5, the test day, participants completed the treadmill load-bearing task and the associated marksmanship assessment. Participants walked while carrying the load at a rate of 3.5 mph for up to four hours. Participants rested 10 min each hr during the four-hr march. Temperature on the test day was approximately 72° F (room temperature).

RESULTS

Although participants were scheduled to walk a total of 200 min (i.e., the 4-hr walk minus the four 10-min rest breaks) no individual completed this task. Walk times ranged from 30 min to 194 min. A one-way ANOVA revealed that walk times (Mean ± S.D.) were not significantly different between diet groups (250 g CHO: 117.0 ± 31.9 min, 400 g CHO: 120.4 ± 41.0 min and 550 g CHO: 144.2 ± 29.3 min). Initially, it was thought the differences in walk times may have confounded the relation between diet and marksmanship performance. However, an analysis of covariance using walk times as the covariate did not prove helpful in explaining marksmanship performance because of the lack of significant differences in walk time between diets.

The effect of load bearing exercise significantly disrupted shot group tightness when shooting for accuracy only (F=4.33, (1,32), $p \leq 0.05$). Table 1 in the Appendix presents means and standard deviations for the various marksmanship measures before and after exercise. The SGT's vertical dispersion (VSGT) also showed this same significant increase after carrying the loaded rucksack (F=4.84, (1,32), $p \leq 0.04$). When shooting for both speed and accuracy, sighting time decreased significantly after the march (F=4.70, (1,32), $p \leq 0.04$). These significant changes in marksmanship due to the exercise may be seen in Figure 1 in the Appendix. None of the accuracy measures when shooting for both speed and accuracy showed any significant differences as a result of the diet, exercise, or a combination of diet and exercise, although participants showed a tendency to be less accurate after exercise when shooting for both speed and accuracy.

No main effect between the different levels of CHO in the diet was observed for any of the rifle marksmanship measures. Table 2 in the Appendix shows the means and standard deviations by level of CHO in the diet. A significant diet by exercise interaction effect existed for SGT (F=4.90, (2,32) $p \leq 0.01$) when shooting for accuracy only. Table 3 in the Appendix shows the individual means and standard deviations for the combined effect of diet and exercise. Duncan's multiple comparison post hoc tests were used to determine individual mean differences of the significant interaction effect. Shot group tightness pre-exercise while consuming the 400 g CHO diet was significantly poorer than the 250 g ($p \leq 0.05$) or 550 g ($p \leq 0.01$) CHO diets. When consuming the 250 g carbohydrate diet SGT was poorer ($p \leq 0.05$), a deterioration of 42%, after exercise. No significant differences existed pre to post exercise for the 400 g or 550 g carbohydrate diets.

DISCUSSION

Shot group tightness declined by 17% after load bearing exercise compared to before. The effect was particularly evident in the vertical direction. A possible explanation is that carrying the rucksack fatigued the upper body, most in the muscles which stabilize the arms vertically (e.g., deltoids, trapezius, spinal erectors). Given the weight of the rifle, the fatigue of muscles providing vertical support to the rifle was apparently enough to impair aiming. The result was an up and down sway of the rifle. These results corroborate those of Knapik et al., (1991) who reported that rifle shooting accuracy was significantly impaired after a load carriage march.

Exercise also significantly affected sighting time. Sighting time after the load bearing march was significantly reduced. As may be seen from Table 1 in the Appendix under the speed and accuracy section, the accuracy measures (DCM, SGT, HSGT, and VSGT) showed slight but non-significant impairment. When physically stressed, less time was taken to sight the target and shooting accuracy was compromised. Previous research found the stressors of acute high altitude exposure (Tharion, Hoyt, et al., 1992), the intense physical exercise involved in litter bearing (Tharion, Rice, Sharp & Marlowe, 1992) and the heat buildup while wearing the chemical protective overgarment (Tharion, Santee, & Wallace, 1992) all produced this same change in sighting time.

The significant interaction effect for SGT when shooting for just accuracy indicates that the greatest impairment occurred after exercise when consuming a 250 g CHO diet (a 42% decrement). This decrement was 7% greater than that observed when consuming the 550 g CHO diet. The SGT decrement with the 550 g CHO diet or the SGT improvement with the 400 g CHO diet were not statistically significant. Although walk times were not statistically significant between diet groups, participants walked an average of 23% farther when consuming the 550 g CHO diet than when consuming the 250 g CHO diet; when consuming the 400 g CHO diet walk times were in between the other two diet groups' times. These results suggest that the 250 g CHO diet was the least effective in being able to maintain physical performance during repeated days of heavy load carriage, while the 550 g CHO diet was best at supporting the demands of sustained heavy load carriage. However, both the 400 g and the 550 g CHO diets appeared to be equally effective in their ability to sustain marksmanship ability following a period of heavy load carriage.

In theory, if all participants walked to total muscular fatigue than they should have reached the same level of muscle glycogen depletion regardless of diet consumed, only differences in walk times should have varied. However, many participants stopped not because of musclar fatigue but rather because of problems such as shin splints or foot blisters. Compounding these problems are the probable differences in motivation levels towards completing the walk. Therefore, different levels of muscle glycogen depletion are likely to exist which in turn probably affected rifle marksmanship. The 250 g CHO diet probably was associated with more muscular fatigue resulting in more tremor which in turn disrupted marksmanship accuracy.

Costill and Miller, (1980) state that diets high in CHO content result in high muscle glycogen stores, which are able to support longer periods of one's endurance performance. This explanation most likely accounts for the smaller decrement seen in SGT while on the 550 g CHO diet. The large pre-exercise SGT mean while consuming the 400 g CHO diet was significantly greater than the two other pre-exercise SGTs. This increase in the pre-exercise 400 g CHO diet was unanticipated and can not be easily explained.

CONCLUSIONS

In summary, soldiers required to march with loads of 45 kg are likely to display impairments in marksmanship. Following the stress of load bearing exercise, soldiers are likely to take less time to accurately sight their target. Marches which last two hours or longer are likely to impair subsequent rifle shooting accuracy to a greater degree when soldiers consume a low (250 g) CHO diet than a medium (400 g) or high (550 g) CHO diet.

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APPENDIX A

FIGURE 1: EXERCISE EFFECTS ON RIFLE MARKSMANSHIP

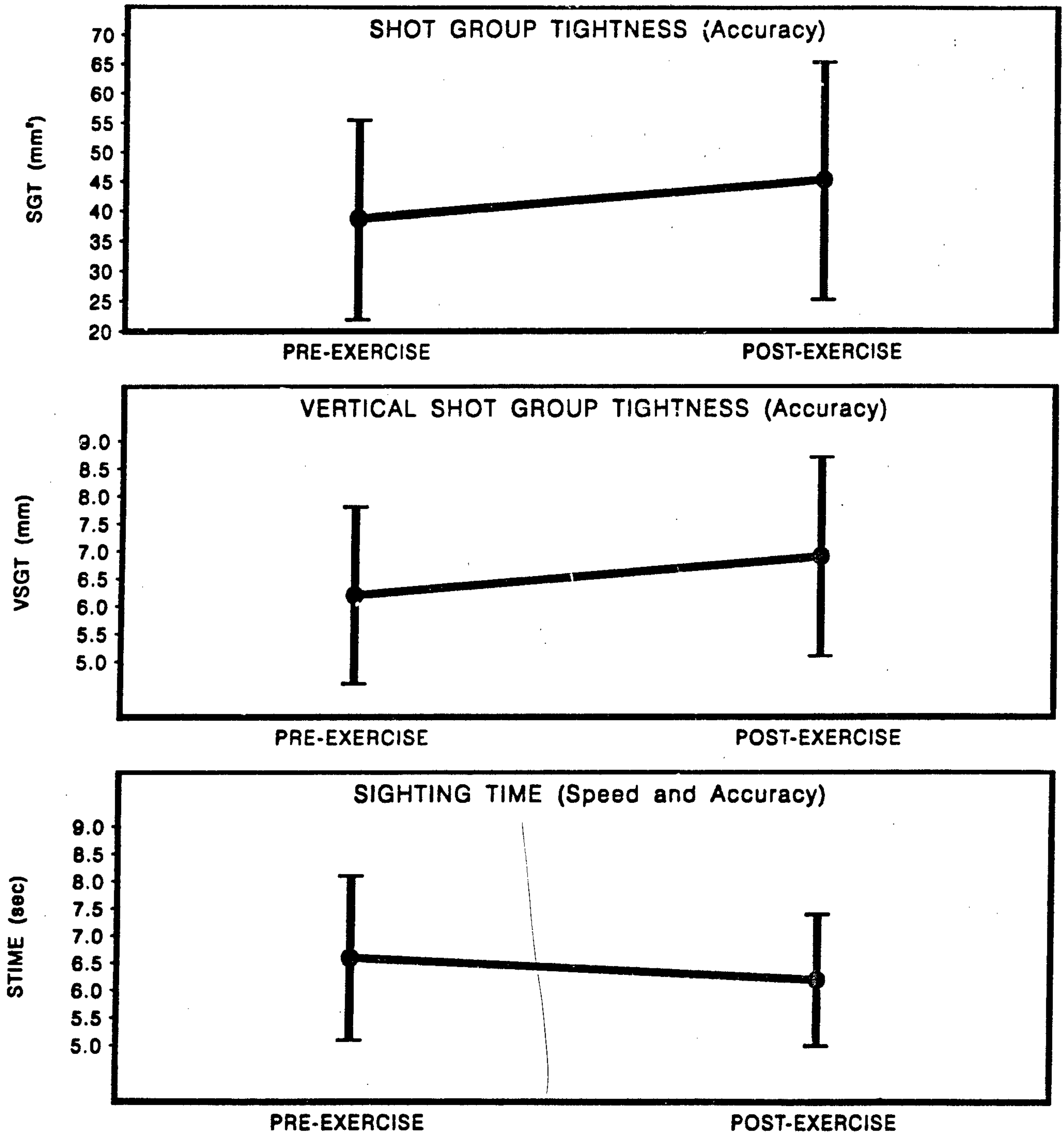

Table 1. Means and standard deviations when shooting for accuracy only and when shooting for speed and accuracy before and after load-bearing exercise.

ACCURACY ONLY

MEASURE	PRE-EXERCISE Mean		PRE-EXERCISE S.D.	POST-EXERCISE Mean		POST-EXERCISE S.D.
DCM	4.1	±	1.1	4.2	±	1.0
SGT *	38.7	±	16.8	45.3	±	20.1
HSGT	6.2	±	1.9	6.4	±	1.4
VSGT *	6.2	±	1.6	6.9	±	1.8

SPEED AND ACCURACY

MEASURE	PRE-EXERCISE Mean		PRE-EXERCISE S.D.	POST-EXERCISE Mean		POST-EXERCISE S.D.
DCM	4.4	±	1.2	4.5	±	0.9
SGT	45.4	±	22.0	47.0	±	22.0
HSGT	6.2	±	2.1	6.3	±	2.1
VSGT	7.0	±	2.3	7.3	±	1.6
STIME *	6.6	±	1.5	6.2	±	1.2

*** Means before and after exercise are significantly different at ($p \leq 0.05$).**

DCM = Distance from Center of Mass (mm)
SGT = Shot Group Tightness (mm^2)
HSGT = Horizontal Shot Group Tightness (mm)
VSGT = Vertical Shot Group Tightness (mm)
STIME = Sighting Time (sec)

Table 2. Means and standard deviations when shooting for accuracy only and when shooting for speed and accuracy by level of carbohydrate in the diet.

ACCURACY ONLY

MEASURE	250g DIET		400g DIET		550g DIET	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
DCM	4.3 ±	1.0	4.3 ±	1.1	4.0 ±	0.7
SGT	44.0 ±	14.9	46.9 ±	18.0	36.1 ±	12.8
HSGT	6.5 ±	1.3	6.8 ±	1.7	5.8 ±	1.0
VSGT	6.7 ±	1.3	6.8 ±	1.3	6.2 ±	1.7

SPEED AND ACCURACY

MEASURE	250g DIET		400g DIET		550g DIET	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
DCM	4.8 ±	0.9	4.5 ±	1.0	4.2 ±	0.8
SGT	53.0 ±	18.7	47.0 ±	18.9	39.8 ±	15.9
HSGT	7.1 ±	1.3	6.4 ±	1.7	5.7 ±	1.7
VSGT	7.2 ±	1.5	7.0 ±	1.5	6.8 ±	1.4
STIME	6.5 ±	1.2	6.1 ±	1.2	6.6 ±	0.8

DCM = Distance from Center of Mass (mm)
SGT = Shot Group Tightness (mm^2)
HSGT = Horizontal Shot Group Tightness (mm)
VSGT = Vertical Shot Group Tightness (mm)
STIME = Sighting Time (sec)

Table 3. Means and standard deviations when shooting for accuracy only and when shooting for speed and accuracy by level of carbohydrate in the diet before and after load-bearing exercise.

ACCURACY ONLY

MEASURE	250g DIET		400g DIET		550g DIET	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Pre-DCM	4.0 ±	1.2	4.5 ±	1.2	3.9 ±	0.8
Post-DCM	4.6 ±	1.0	4.2 ±	1.2	4.0 ±	0.9
Pre-SGT	* 36.3 ±	14.6	# 50.5 ±	19.3	@ 30.6 ±	10.2
Post-SGT	51.7 ±	18.4	43.2 ±	23.2	41.6 ±	18.8
Pre-HSGT	5.8 ±	1.5	7.4 ±	2.2	5.6 ±	1.4
Post-HSGT	6.4 ±	1.5	6.1 ±	2.4	6.0 ±	1.5
Pre-VSGT	6.4 ±	1.7	6.7 ±	1.6	5.6 ±	1.4
Post-VSGT	7.0 ±	1.6	7.6 ±	1.3	6.9 ±	2.4

*** Significant difference Pre and Post 250 g Diet SGT ($p \leq 0.05$)**
 # Significant difference Pre 250 g and 440 g Diet SGT ($p \leq 0.05$)
@ Significant difference Pre 400 g and 550 g Diet SGT ($p \leq 0.01$)

SPEED AND ACCURACY

MEASURE	250g DIET		400g DIET		550g DIET	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Pre-DCM	4.6 ±	1.2	4.5 ±	1.3	4.1 ±	1.1
Post-DCM	4.8 ±	0.9	4.5 ±	0.9	4.3 ±	0.9
Pre-SGT	50.7 ±	19.2	48.0 ±	27.0	38.9 ±	20.2
Post-SGT	54.9 ±	27.9	46.0 ±	19.6	40.2 ±	16.0
Pre-HSGT	6.9 ±	1.5	6.3 ±	2.2	5.5 ±	2.4
Post-HSGT	7.3 ±	2.2	6.5 ±	2.0	6.0 ±	2.1
Pre-VSGT	7.1 ±	1.5	7.2 ±	2.6	6.7 ±	2.8
Post-VSGT	7.2 ±	2.1	6.9 ±	1.4	6.9 ±	1.5
Pre-STIME	6.6 ±	2.0	6.4 ±	1.3	6.9 ±	1.2
Post-STIME	6.5 ±	1.6	5.9 ±	1.2	6.2 ±	0.9

DCM = Distance from Center of Mass (mm)
SGT = Shot Group Tightness (mm^2)
HSGT = Horizontal Shot Group Tightness (mm)
VSGT = Vertical Shot Group Tightness (mm)
STIME = Sighting Time (sec)

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